DREAM2's Space Environmental Studies with Exploration Applications

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NASA/Goddard Space Flight Center

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SERVI SOLAR SYSTEM EXPLORATION RESEARCH VIRTUAL INSTITUTE

DREAM2

Outline:

- What is SSERVI and DREAM2?
- Example #1: Plasma-surface interactions and human systems
- Example #2: Exosphere and gases, and the ARM
- Example #3: Surface interactions at the Lunar Poles
- Example #4: Radiation interactions, safe times, and hiding

  [for each Example, provide a new science and new exploration perspective]
- Future studies & Conclusions

NASA LUNAR SCIENCE INSTITUTE

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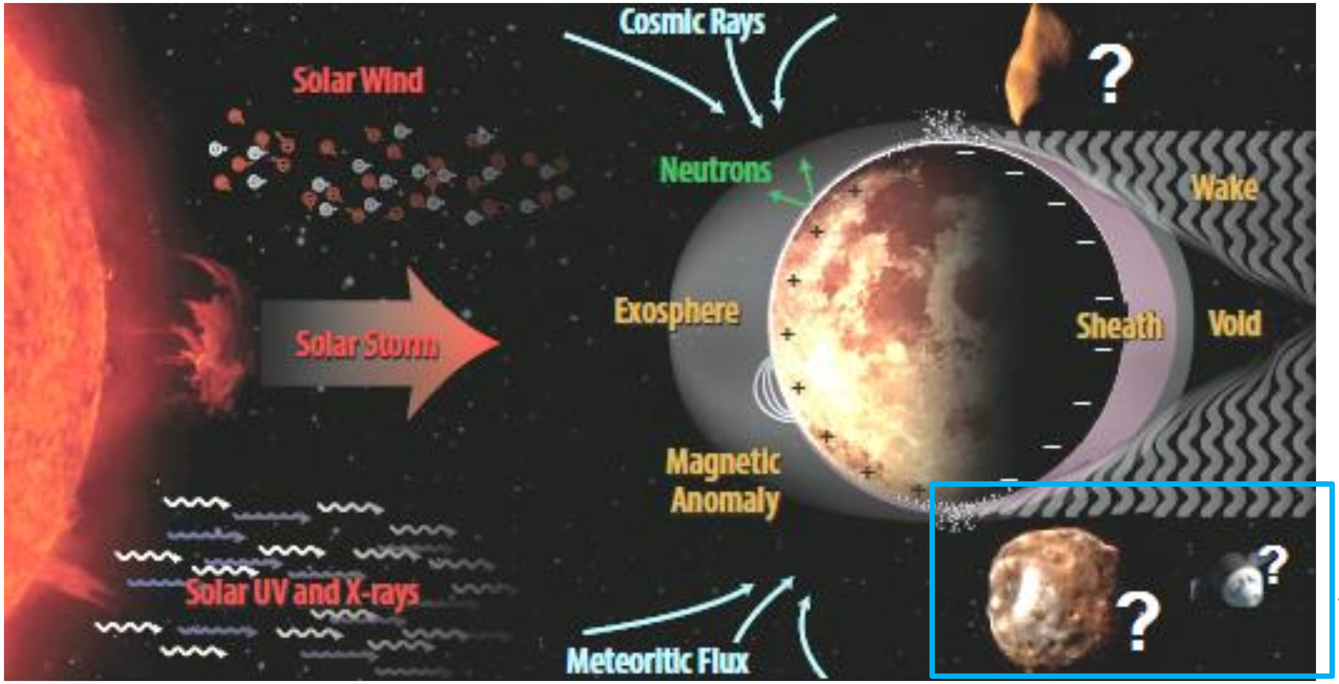
What is SSERVI and DREAM2?

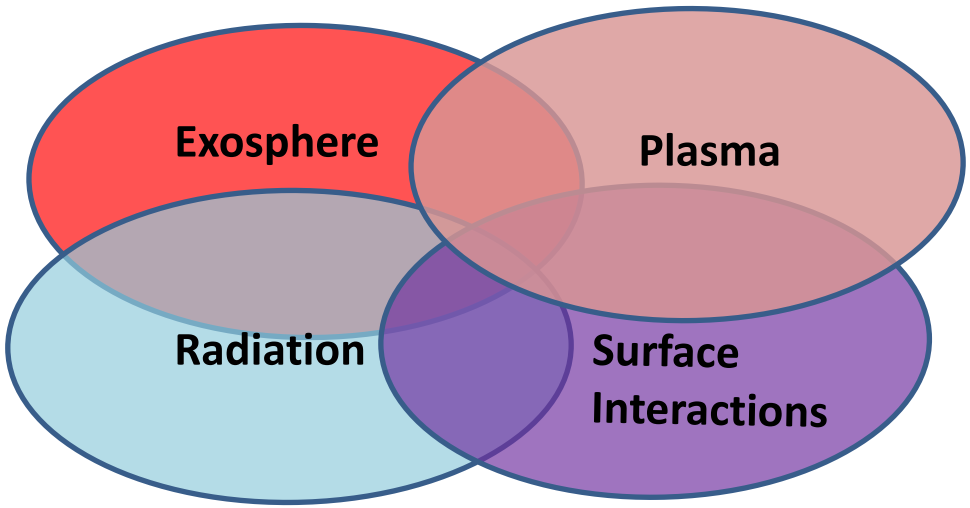
- In 2007, NASA’s Planetary Division and ESMD formed a **virtual institute** dedicated to **the science-exploration connection** at the Moon
  - Analogous to NAI, not ‘brick and mortar’ building, but connect via modern comm technology
- In 2008, 7 science teams or ‘nodes’ were selected as part of NASA Lunar Science Institute centered at ARC (D. Morrison and now Y. Pendleton Directors).
- In 2013, NLSI changed to Solar System Exploration Research Institute (SSERVI)
- Expanded targets to include Mars’ moons and asteroids, other places of interest for exploration
- *Dynamic Response of the Environment at Asteroids, the Moon and moons of Mars (DREAM2)*



body-body interactions

- Theory, modeling, data center emphasizing the space environment- airless body connection
- “How does the highly-variable environmental energy at an airless body affect volatiles, plasma, new chemistry, and surface micro-structure?”
- Emphasize the dynamics and extreme events – solar storms and human interaction
- Provide support to missions like LADEE, LRO, Resource Prospector
- 35 investigators from 12 partnering institutions, GSFC PI.

Dynamic Response of Environments at Asteroids, Moon, and moons of Mars (DREAM2)



Fundamental Themes

-Exospheres

-Plasmas

-Particle Radiation

-Surface Interactions

"How does the highly-variable environmental energy at an airless body affect volatiles, plasma, new chemistry, and surface micro-structure?"

Applied Themes:

-Extreme Events

-Applications to missions and HEO

Focus on common processes at all target bodies

DREAM2 Team

- **Exospheres:** R. Killen ,R. Vondrak (GSFC), D. Hurley (APL), M. Sarantos (UMBC), A. Colaprete (ARC), D. Glenar (UMBC), M. Burger (Morg. St.), R. Hodges (LASP),

- **Plasmas:** W. Farrell, T. Jackson, C. Cheung, T. Stubbs, M. Collier, (GSFC) , G. Delory, J. Halekas, A. Poppe, S. Bale (UCB), M. Zimmerman (APL)

- **Key International Collaborator:** M. Holmstrom (IRF)

GSFC, UCB, UNH, APL, UMBC, ARC, CUA, Morgan St., ORNL, SETI, SWRi, LASP, Howard, LPI

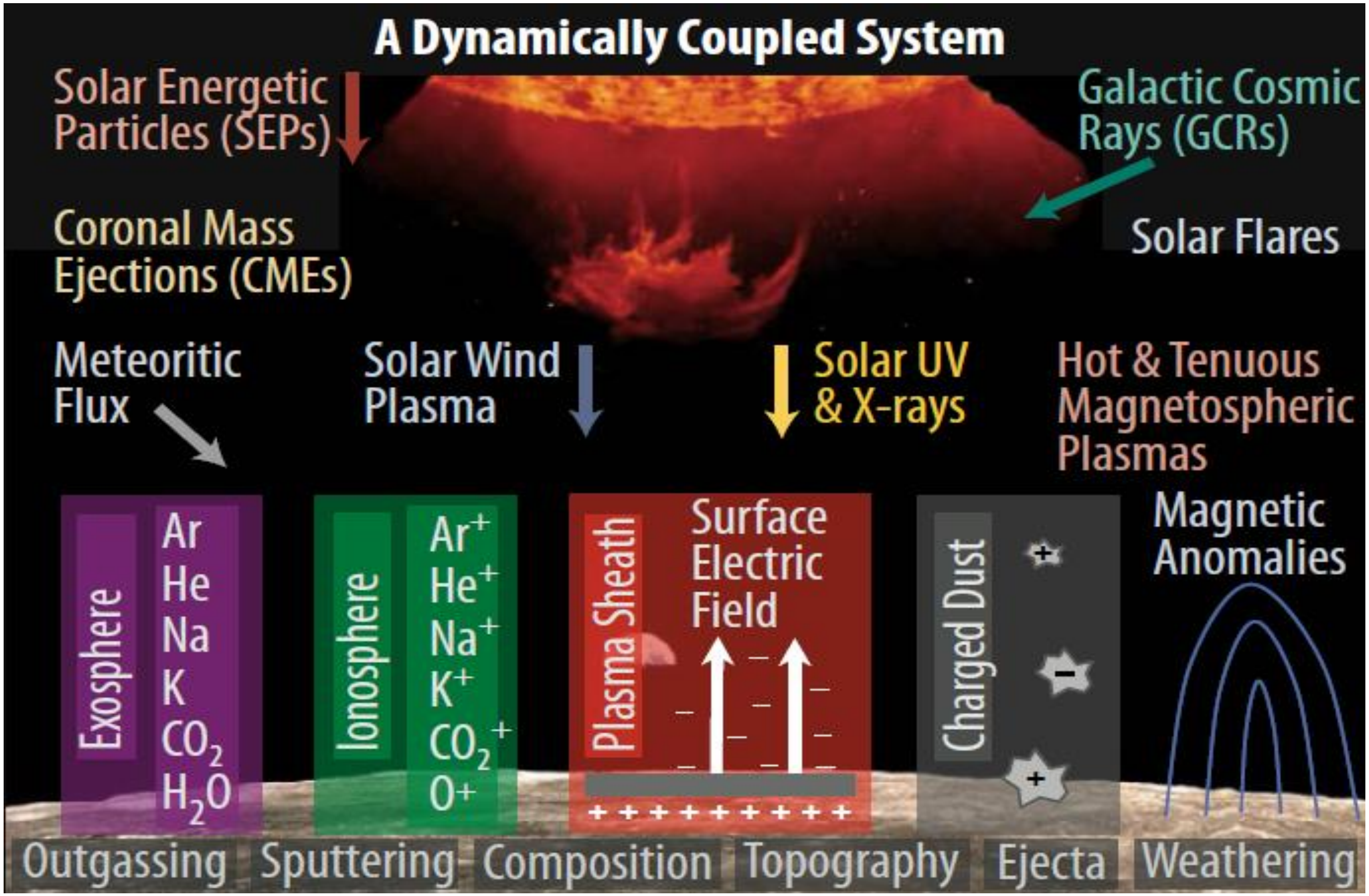
- **Radiation:** N. Schwadron, H. Spence, A. Jordan, J. Wilson (UNH) J. Cooper, Y. Zheng (GSFC), A. Pulkkinen (GSFC), C. Zeitlan (SWRI)

- **Surface Interactions:** J. Keller, M. Loeffler, R. Hudson, S. Noble (GSFC) R. Elphic (ARC), J. Marshall (SETI), F. Meyer (ORNL), P. Clark (CUA), P. Misra (HU), J. McLain (NPP)

- **Applications:** J. Bleacher (GSFC), others

- **EPO:** L. Bleacher (GSFC), A. Jones (LPI)

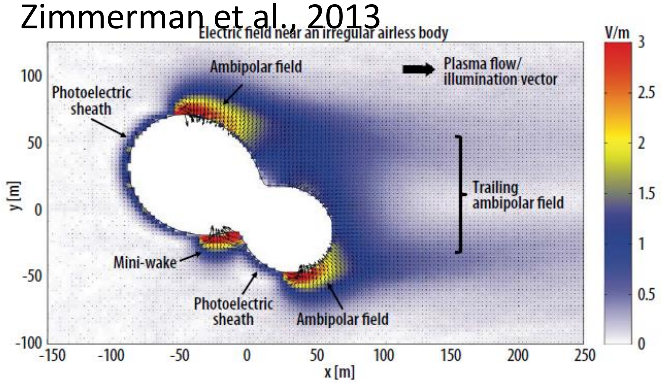
Environmental energy and matter incident at surface: Drives a response



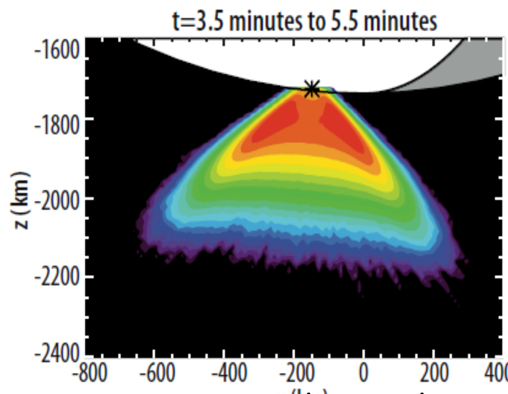
Exosphere = Collisionless atmosphere

Snap-shots of DREAM2 environmental modeling tools for science and exploration

Zimmerman et al., 2013

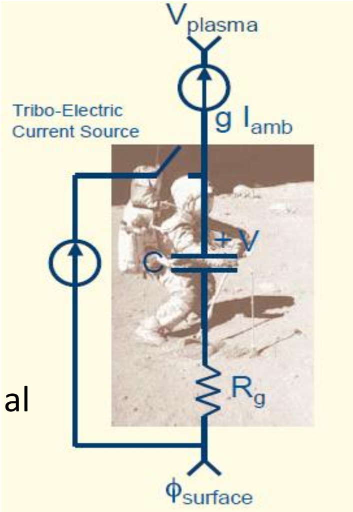


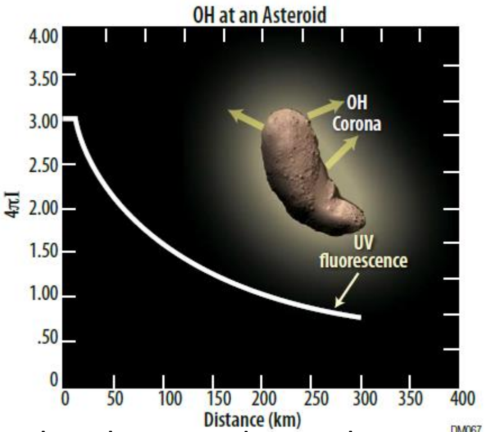
Plasma simulations of solar wind/asteroid interaction regions and local surface charging



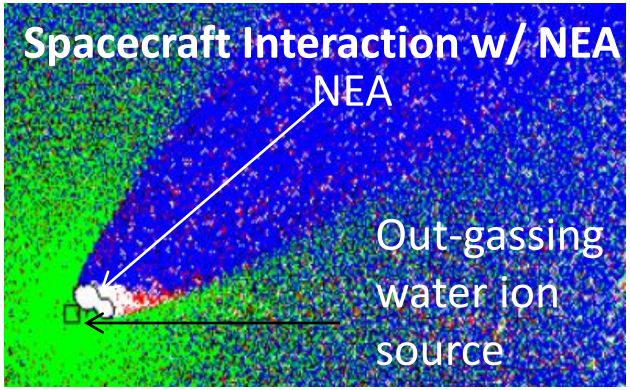
Impact vapor release above applied to LCROSS impact [Killen et al., 2011]

Human system charging & electrical dissipation models [Jackson et al 2011]





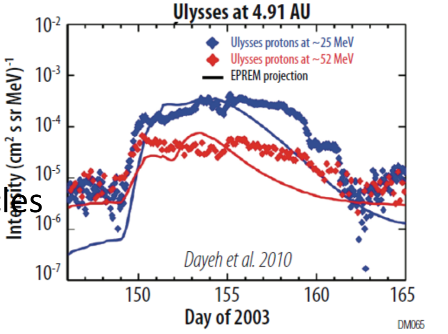
Volatile release and exosphere formation for ISRU prospecting. Model of expected UV profile from vaporized gases at body at 2 AU [Morgan and Killen,1998]



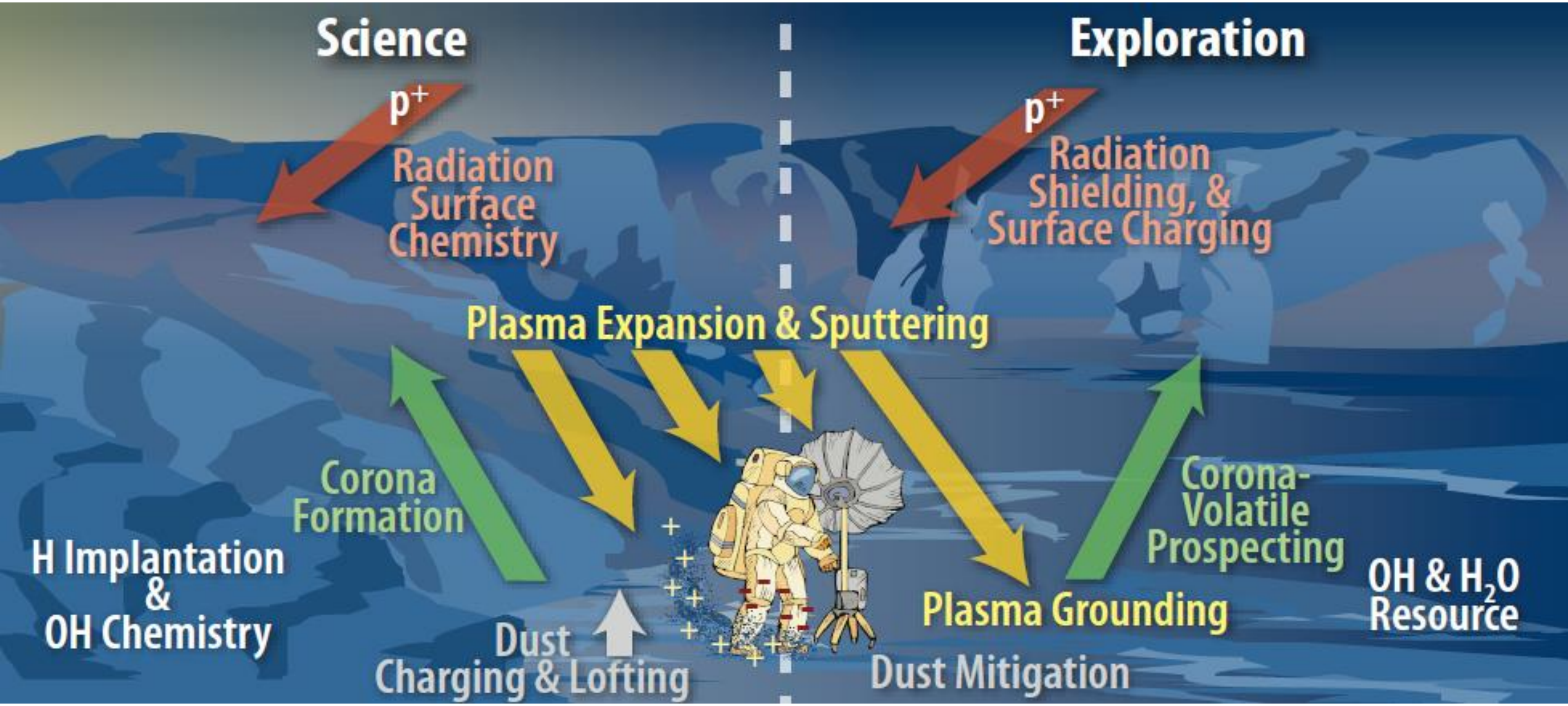
Model of spacecraft out-gassing water ion cloud interacting with an NEA [Farrell et al, 2013]

Dust electrostatics & cohesion [Marshall et al 2011]

Predictions of solar storm energetic particles to other bodies

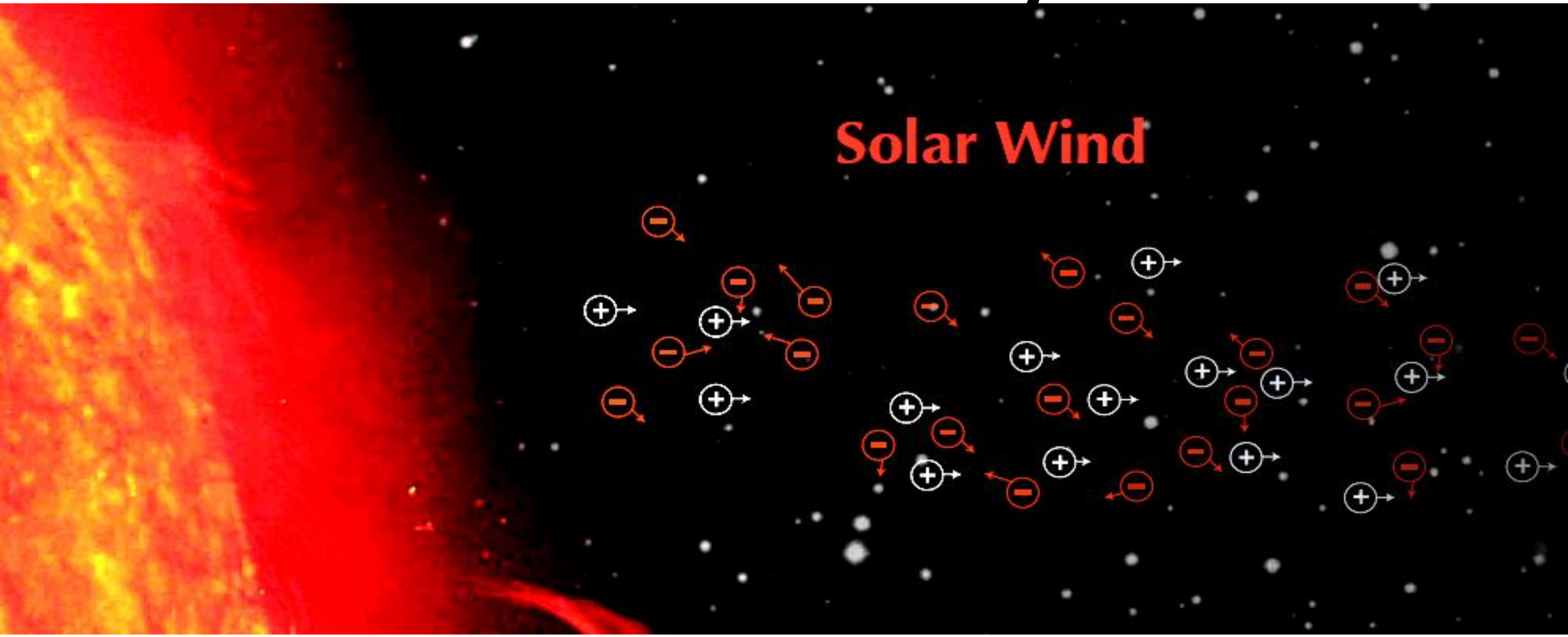


Dual Nature of the Space Environment



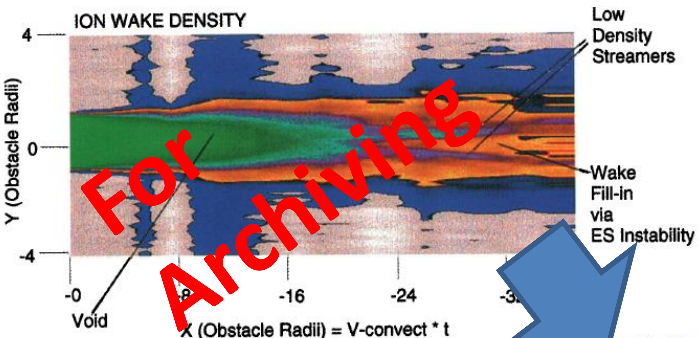
Every component of the environment studied by DREAM2 has both a science AND exploration manifestation

Example #1: Solar wind interaction at an airless body

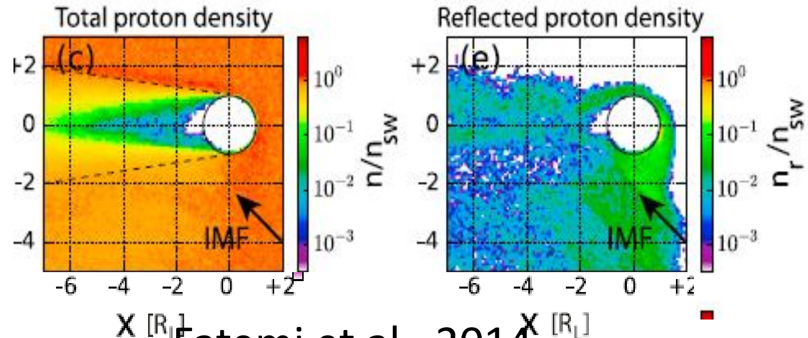


- Solar wind – tenuous ionized gas: Plasma is the 4th State of matter, most mass in universe, good example: our sun
- Protons and electrons at $5/cm^3$ streaming at 400 km/sec, temperature near 100000K
- Airless body is a obstacle in this conductive plasma ‘fluid’ flow!
- Outside magnetosphere, bodies and human systems are part of this solar ‘electrical circuit’

Under NLSI’s DREAM – Evolution of Solar Wind/Moon interaction

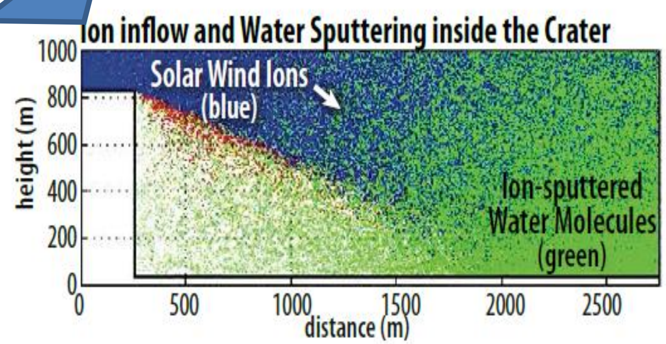


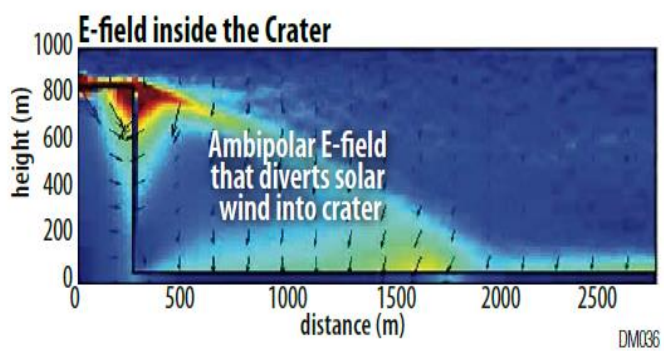
WIND Wake picture 1998

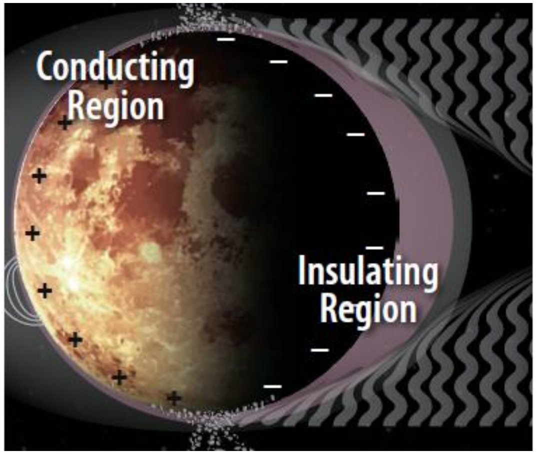


Fatemi et al., 2014
(DREAM2 UCB post-doc)
Reflected protons on lunar wake

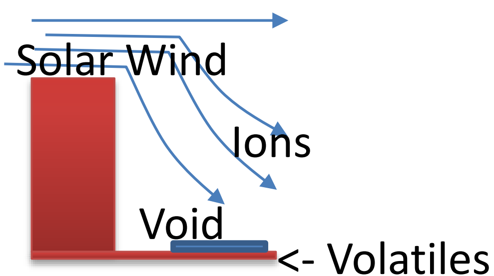
Zimmerman et al. 2011
(DREAM GSFC post-doc)
plasma ‘mini-wake’
in polar craters



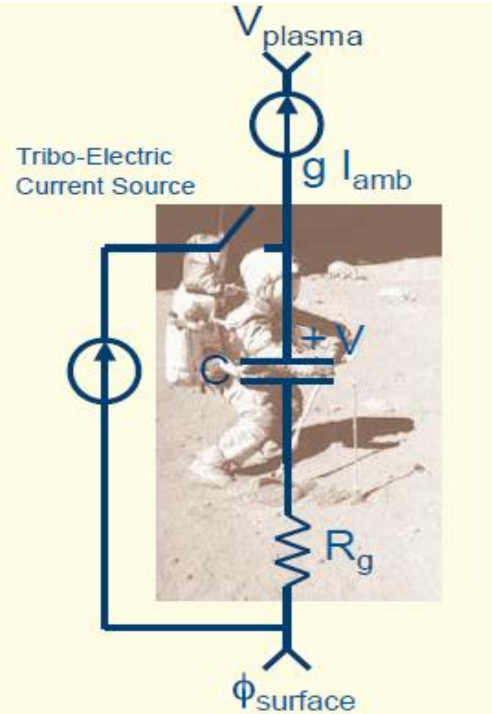


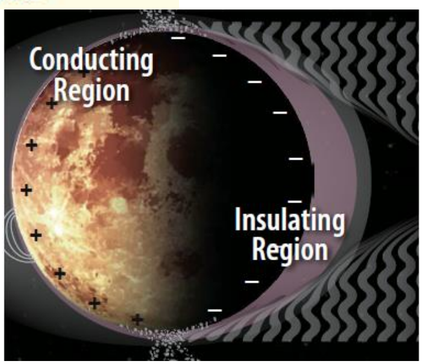


Contrasting electrical nature of the Moon



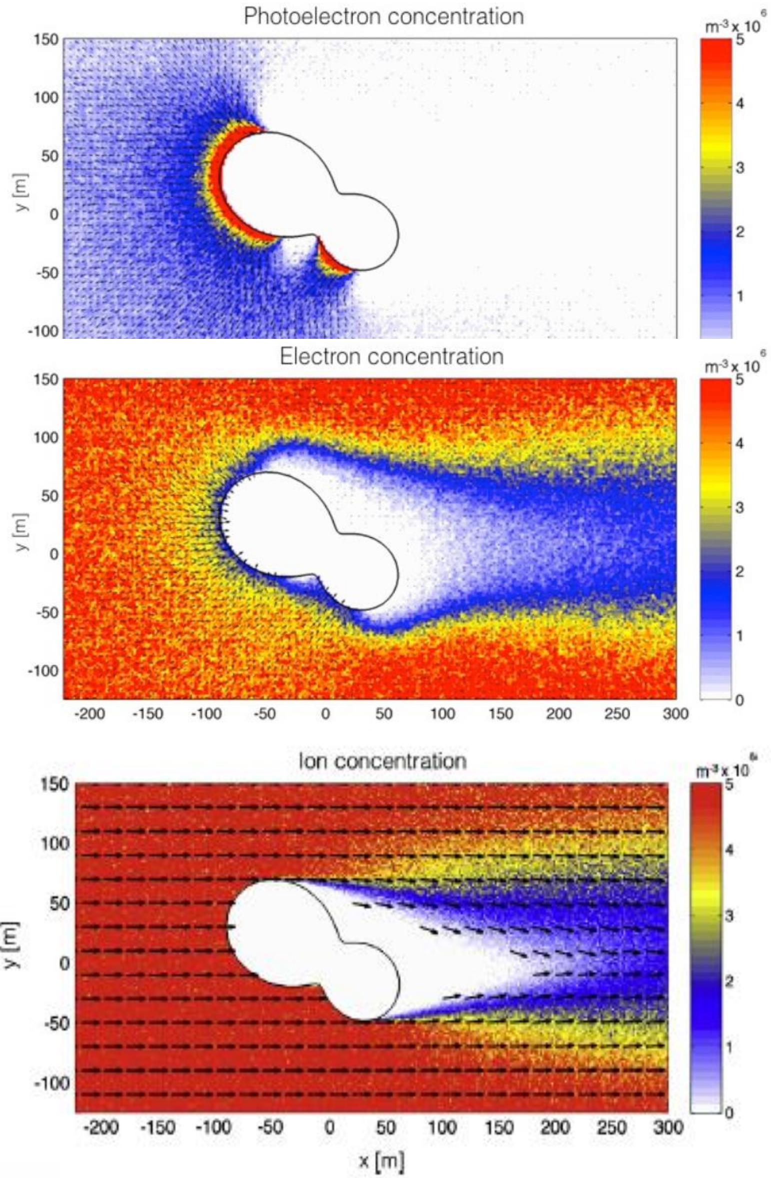
Differential Charging of Human Systems



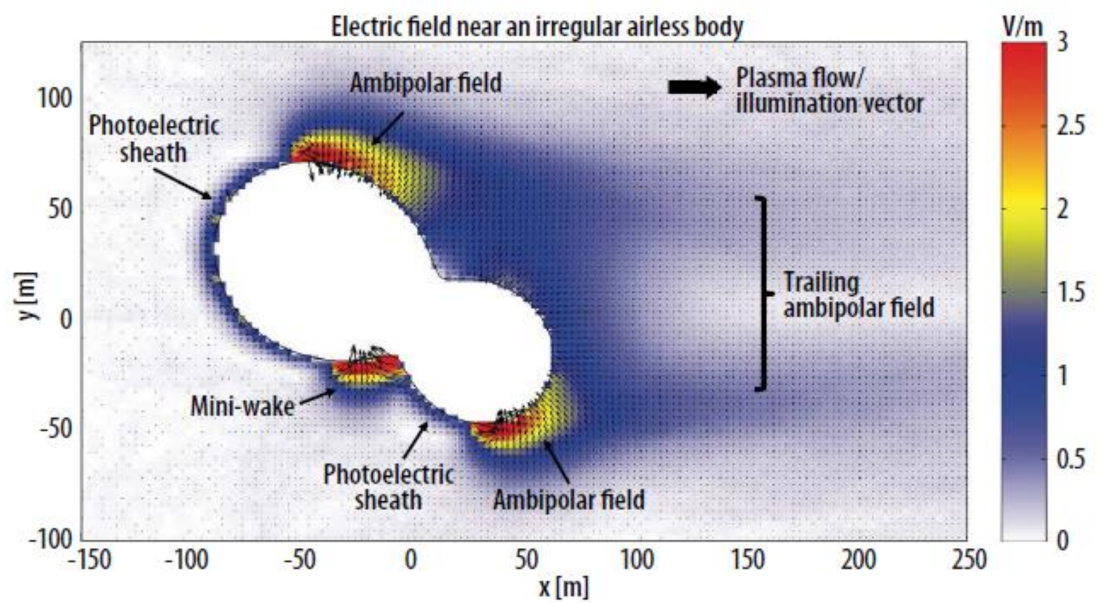


- **NLSI study:** Roving on the Moon [Jackson et al., 2011]
- $dQ/dt = S_{tribo} – L_{plasma} - L_{ground}$
- Not grounded to surface, but plasma
  – In lunar nightside (and polar craters) electrical conductivity of regolith is $\sigma < 10^{-15}$ S/m (less conductive than paraffin)
  – Electrical Dissipation time $\tau = \varepsilon_o/\sigma > 10^4$ s
- Where there is a lot of plasma, charge buildup is easily dissipated
- However, on nightside and in polar craters, where cut-off from bulk of plasma, …lose access to your 'electrical ground'
- Dissipation times to plasma anomalously longer

Solar Wind Interaction at an Asteroid



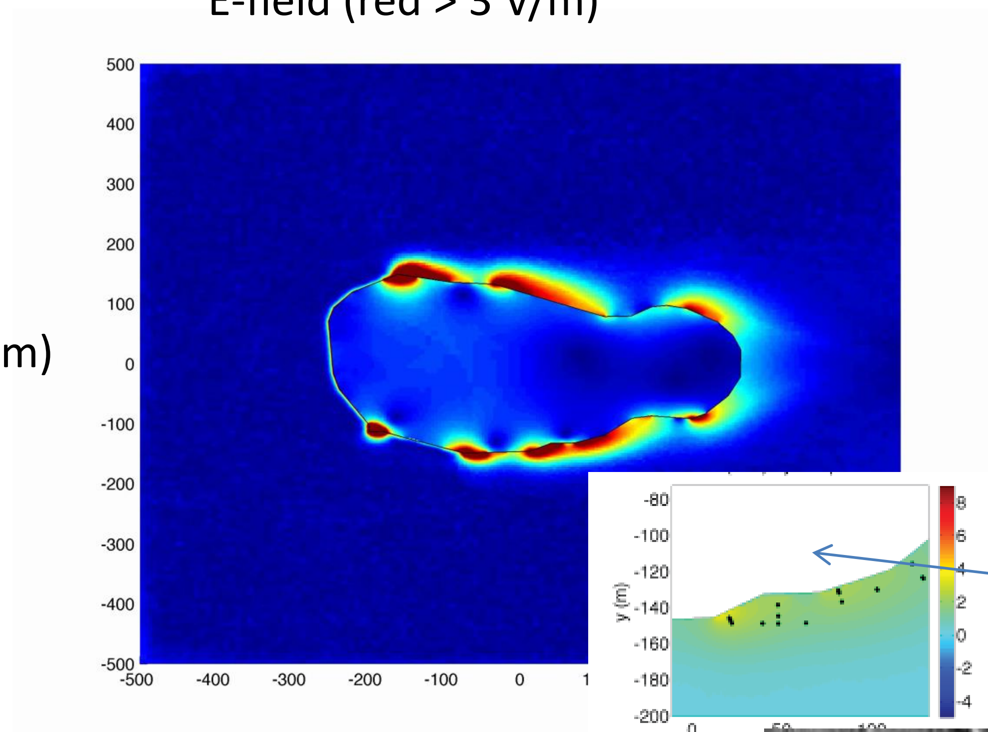
- Recent Study: Zimmerman et al., 2014, Icarus
- New tree code from the last year of his post-doc at GSFC
- Contrasting nature (again)



Science Application: Dust transport on Asteroids

E-field (red > 3 V/m)

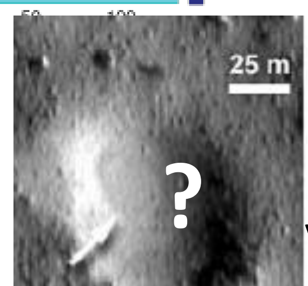
Y (m)



E-fields at Itokawa X (m)

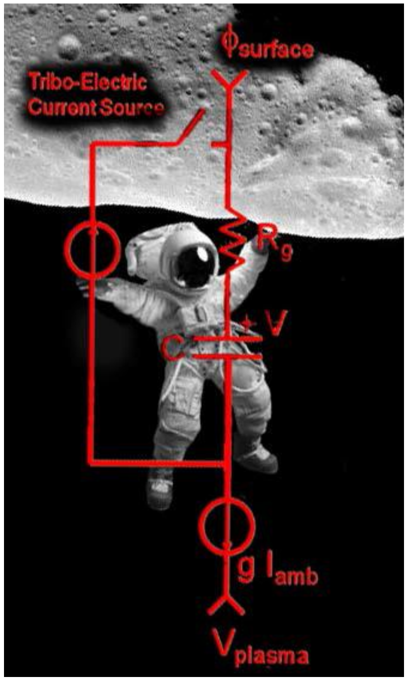
Tree code has an adaptive mesh to allow finer resolution near small scale surface Features.

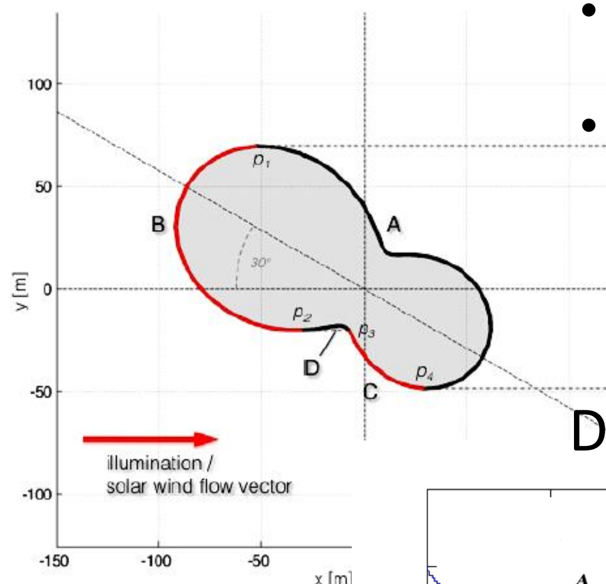
- Given tree code model of the E-field and sheath, can consider electrostatic dust transport
- Examine dust ponding on Eros (follow-up to Colwell et al., 2005, Veverka et al, 2001)
- **Hartzell and Zimmerman** working on this using Itokawa sim E-fields [Hartzell and Zimmerman DPS presentation, 2014]



Veverka et al., 2001,
Eros 'pond'

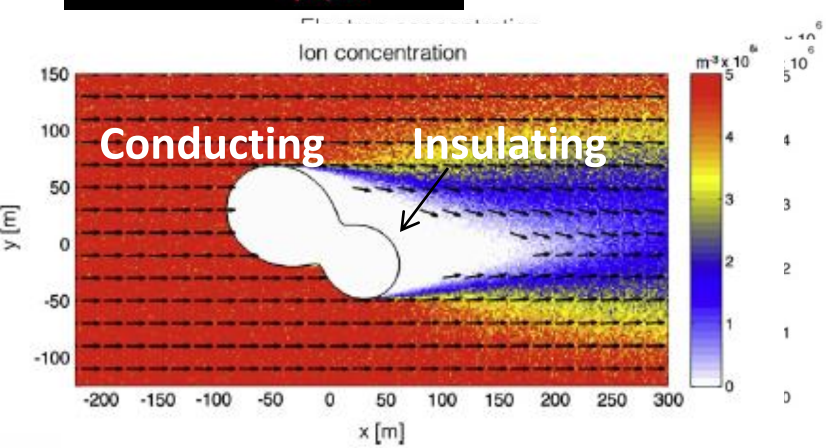
Exploration: Human Exploring at an Asteroid

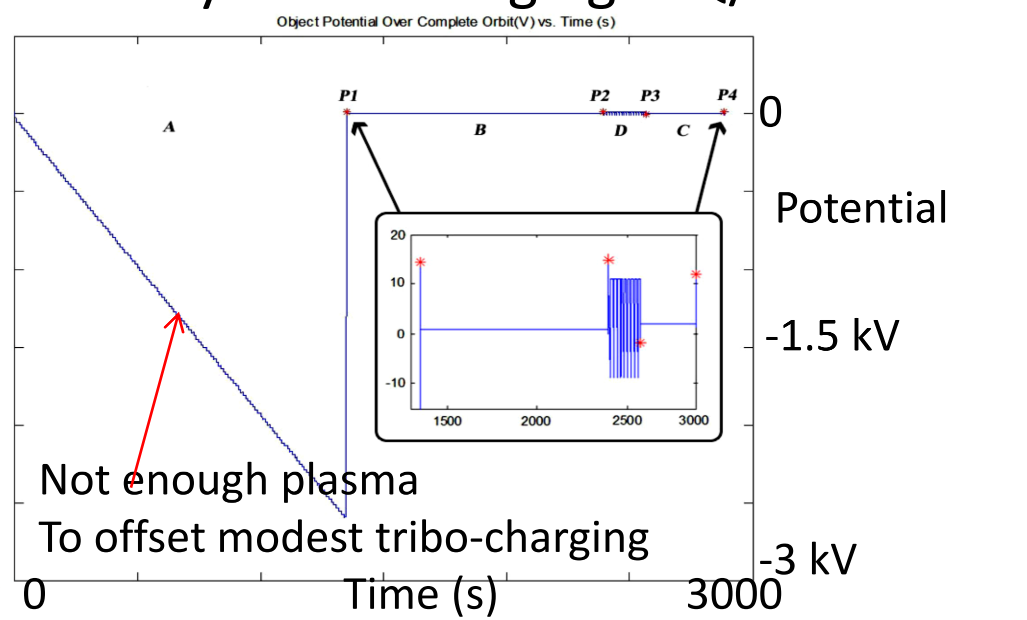




- SSERVI: Jackson et al., 2014, LPSC
- Now take Zimmerman asteroid model and now ask how an astronaut would charge if traversing over the surface by pushing along with hands

Dynamic charging: dQ/dt = S - L





Example #1 Key Take-away:

Given new basic science tool (tree code and solar wind plasma interactions at an asteroid) there is automatic exploration application and understanding in SGK on

-Pursing issue of electrical grounding on exposed bodies

For Exploration Consideration:

-Untethered astronaut should explore asteroid on dayside of body or in high local plasma environment to avoid plasma-starved locations

-Space suits should have metallic outer-skin to obtain greater electrical connection to the plasma (ground) [from Jackson et al., 2011]. Increase return current collection area.

-There are conductivity requirements for spacecraft, and by analogy, should have the same for astronauts pressure vessels immersed in the conductive space environment

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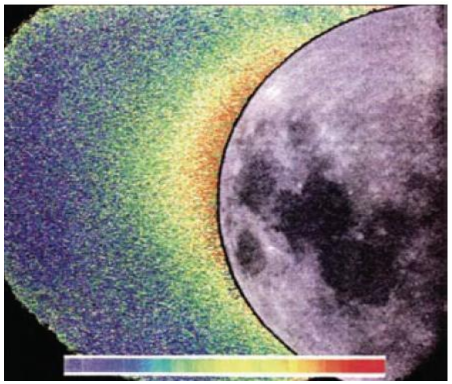
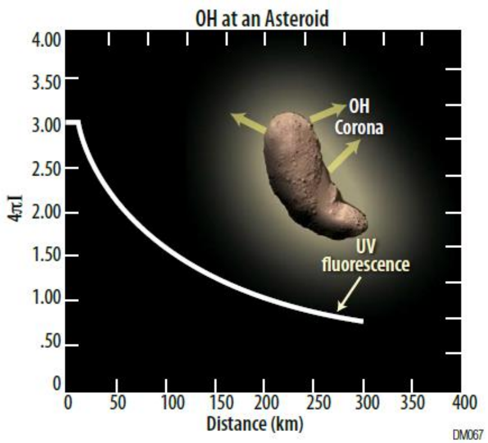
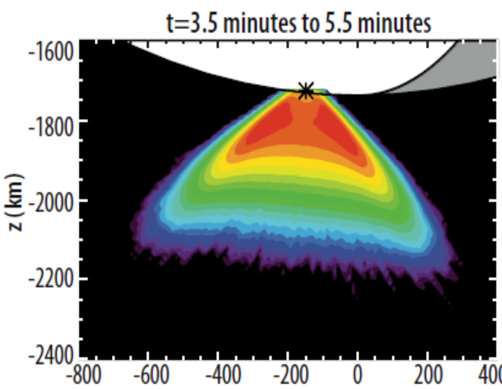
Example #2: Exospheres and Gas Environments



Observations of
lunar sodium
Atmosphere [Potter and Morgan, 1998]



Volatile release and exosphere formation for ISRU prospecting. Model of expected UV profile from vaporized gases at body at 2 AU [Morgan and Killen,1998]



Impact vapor release above applied to LCROSS impact [Killen et al., 2011]

- Exosphere: Low density, collision-less atmosphere
- Moon: Surface-bounded exosphere
- LADEE dedicated mission
- Gases released by space environment effects
  - Thermal diffusion
  - Photon and electron desorption
  - Plasma sputtering
  - Micro-meteoroid Impacts!!

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Science: Mars-induced Exosphere at Phobos

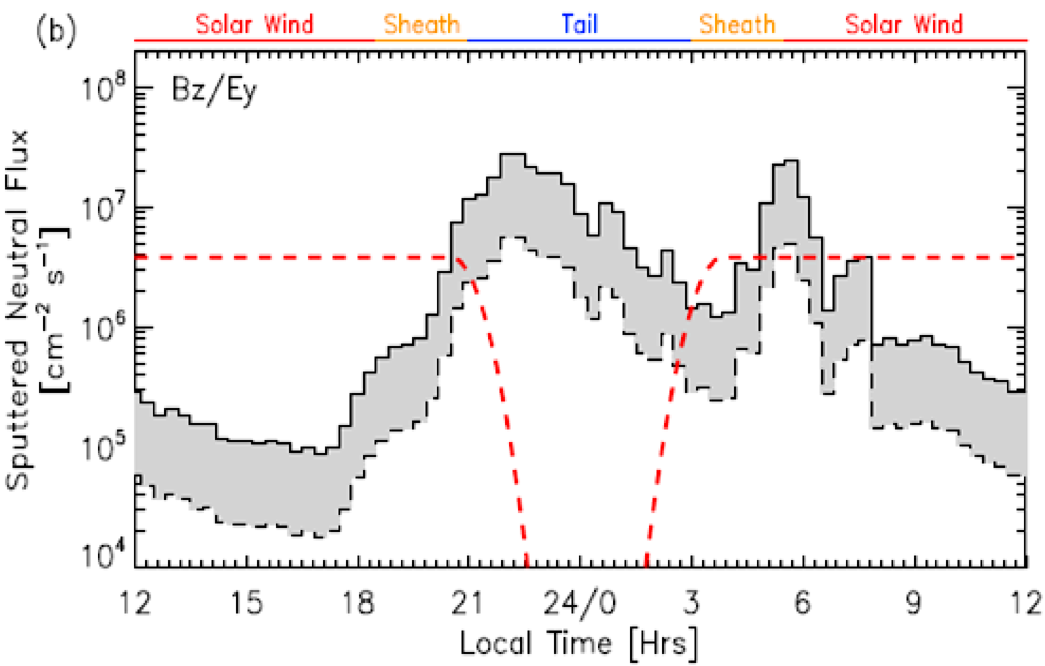
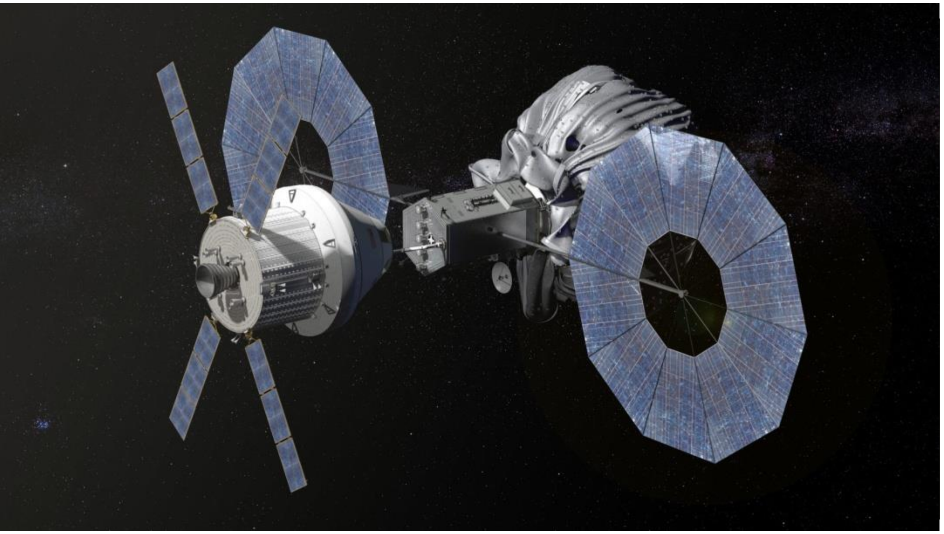


Figure 2. A comparison of the neutral sputtered flux from Phobos induced by solar wind protons and alphas (dashed red lines) and Martian planetary O^+ (solid black lines) for (a) Parker spiral and (b) B_z IMF conditions. The grey-shaded region denotes variability in the O^+ escape flux induced by the varying position of the Martian crustal fields with respect to the subsolar point [*Fang et al.*, 2010].

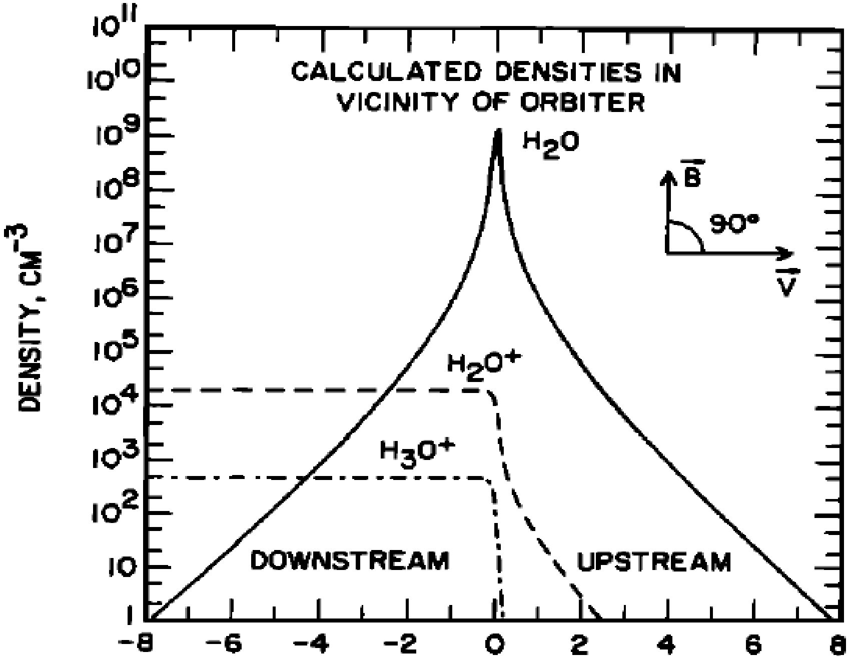
- Poppe and Curry [JGR, 2014]
- Heavy ions (O^+) from Mars' atmosphere hit Phobos…kick off atoms
- Predicts a donut-shaped neutral torus at r = 2.7 R_m
- DREAM2 prediction for MAVEN validation
- Example of Gas body-rocky body interaction

Exploration/ARM: Orion as a water source at the NEA



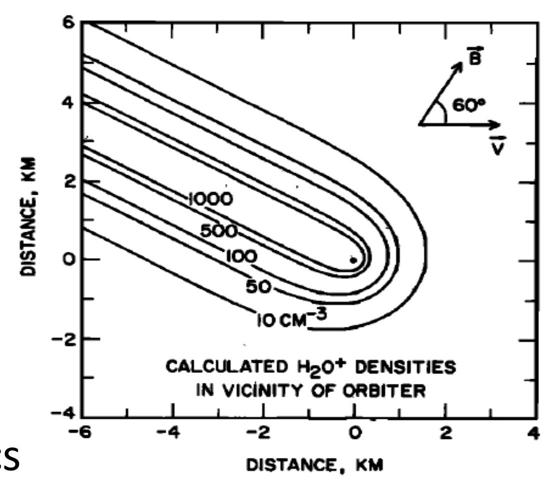
- Joint DREAM2/VORTICES effort
- Presented at 2014 SSERVI/ESF
- Asteroid Environment: Fragile!
- Environmental impact from human system interaction:
  - Spacecraft outgassing & NEA surface water implantation

Orion Water Outgassing



- **Shuttle as an analog**
- Info garnered during the 1985 SpaceLab-2 Mission using Plasma Diagnostics Package [Paterson and Frank, 1989]
- **Nominal outgassing:** ~10^9/cm^3 in vicinity and 10^6/cm^{3}at 1 km [Paterson and Frank, 1989]
- **Large dumps:** STS-128 dumps ~70 kg, 10^{17}/cm^3 in vicinity & 10^{11}/cm^3 at 1 km
- Orion should be the dominant atmosphere: Lots of Water!

Plasma Diagnostics Package



Paterson and Frank, 1989

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VORTICES

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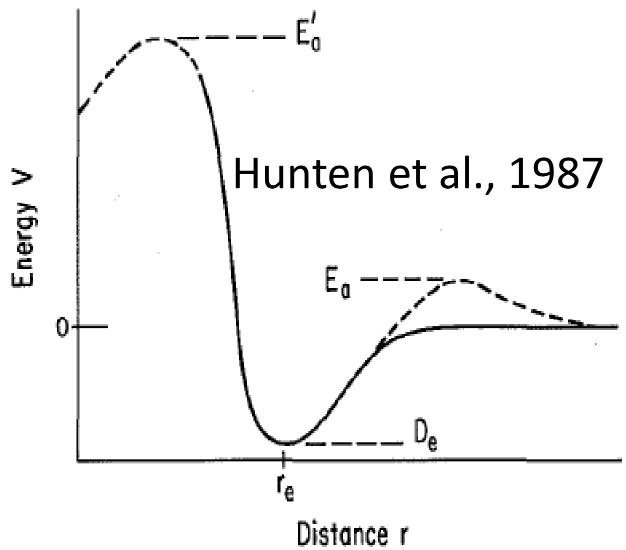
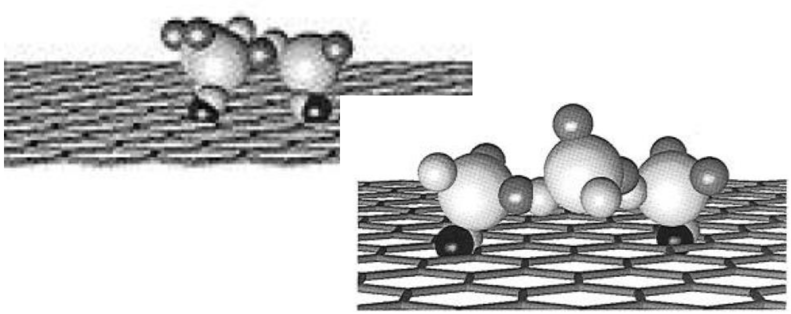
Orion Water-Surface Interaction: Thermal Desorption



Hunten et al., 1987



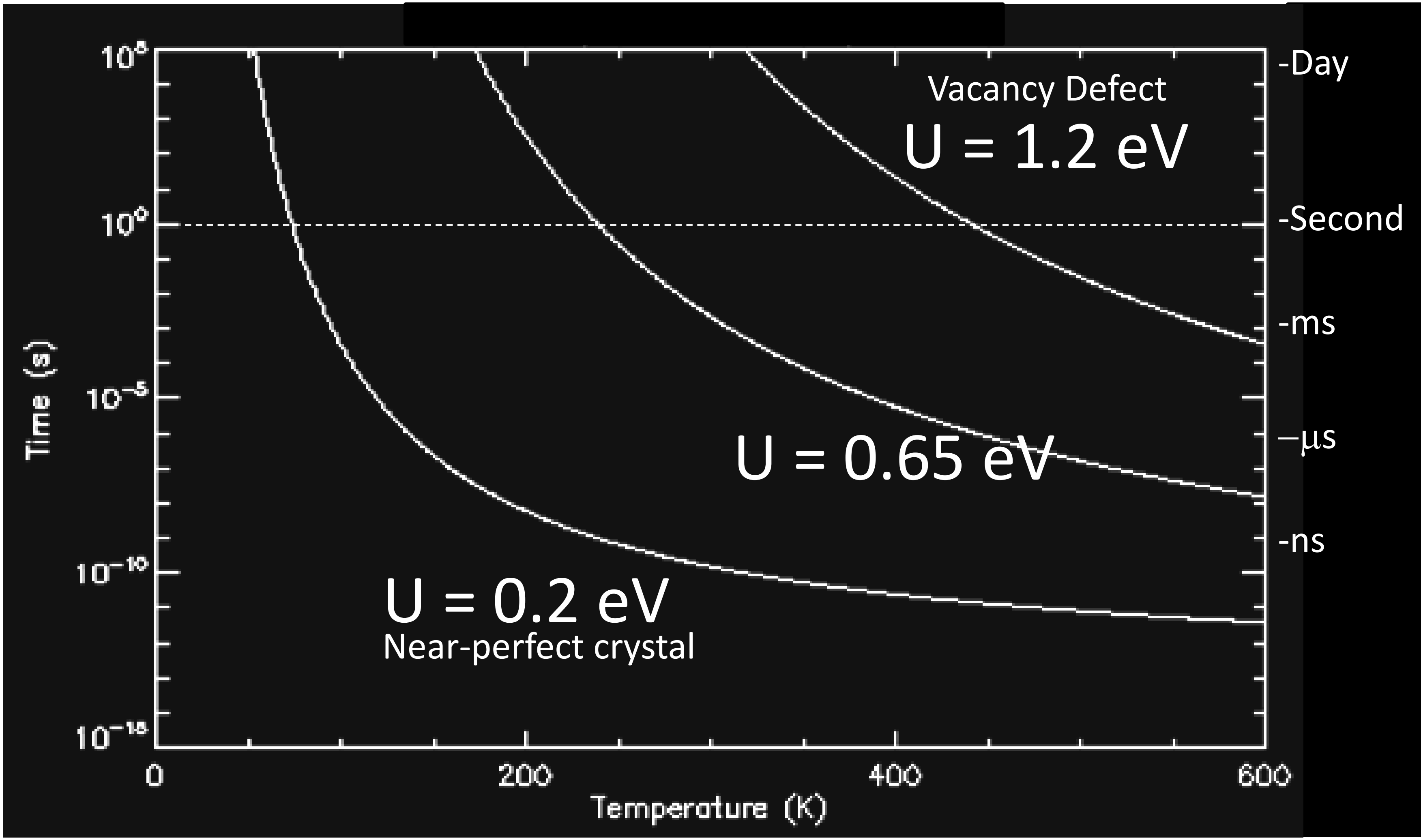
Muller et al., 1996: Solid state model of water adsorption at defect sites

- Water ‘sticks’ to surface (adsorbed)
- **Thermal desorption:** Warm surface releases water
- **VORTICES team:** Temperature-Programmed Desorption (TPD) of water [Hibbitts et al. 2011; Poston et al., GaTech thesis, 2013]
- Polanyi-Wigner Eq.

$$\tau_{res} \sim \tau_{td} \sim \mathbf{10^{-13}s\ e^{U/T}}$$

  - U = Activation Energy (eV)
  - T= Temperature (eV)
- Large U typically associated with crystal irregularities & vacancy defects

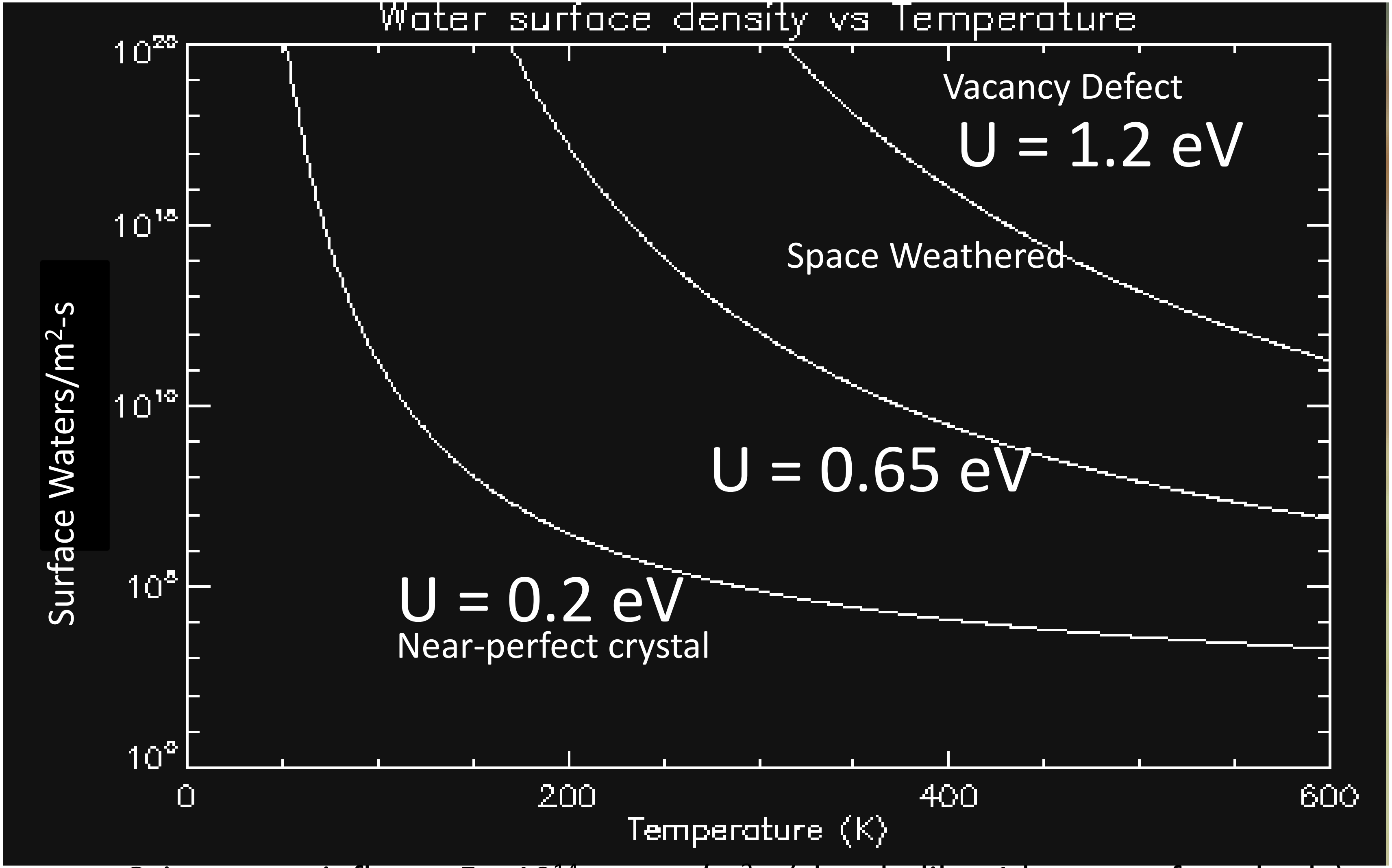
Residency or ‘Sticking’ Time vs Temperature



-Strong function of both temperature and surface crystal defects that determine U

-Nice discussion of defects and water retention in Dyar et al. [2010]

Dynamic Equilibrium Solutions



Orion water influx at 5 x 10^{14} waters/m^2-s (shuttle-like, 1 km away from body)

Key Takeaway: Temperature is important, but defects (U) are the defining variable (U/T)

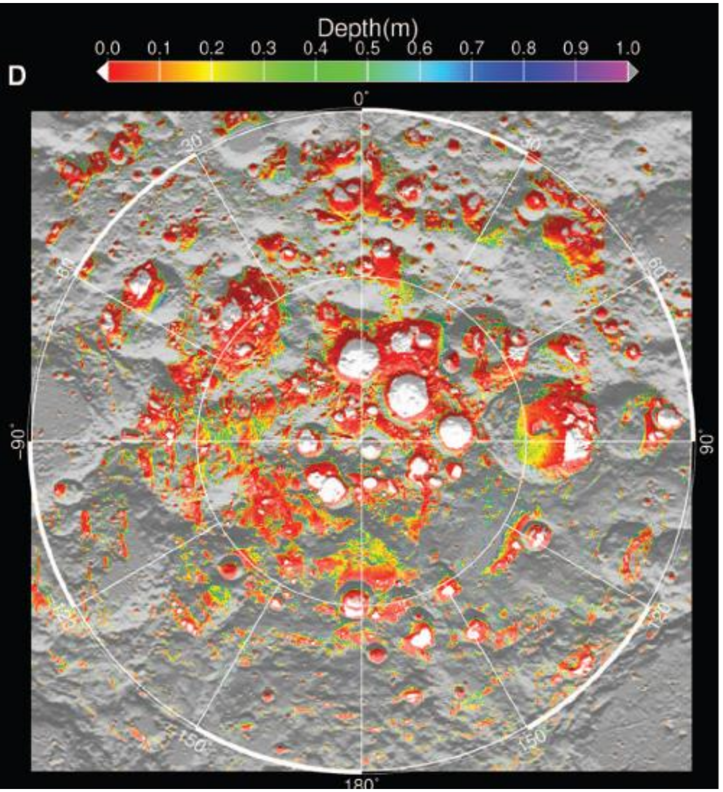
Example #2 Key Take-aways

- ❑ Any object exposed directly to the space environment will outgas material– impacts & plasma energetic enough to release vapor
- ❑ For systems with **humans onboard,** the spacecraft is likely a dominate source of gas (compared to the exposed body).
- ❑ Adsorption (atom 'sticking') is a function of surface material exposure

For Exploration Consideration:

- Water dumps: Don't do water dumps in the near vicinity of the body
- Cover asteroid: If not yet decided, it may be of benefit to cover asteroid
- During ARM: Monitor water build-up via 3 micron IR observations
- Build a **Defect Garden**: Area on asteroid that is monitored for adsorbed water over time (regolith, turned-over regolith, impacted regolith, sample strips, etc). Like Long Duration Exposure Facility (LDEF).

Example #3: South Polar Crater Surface Interactions



Allowable locations for ice at south pole based on thermal model, Paige et al. 2010

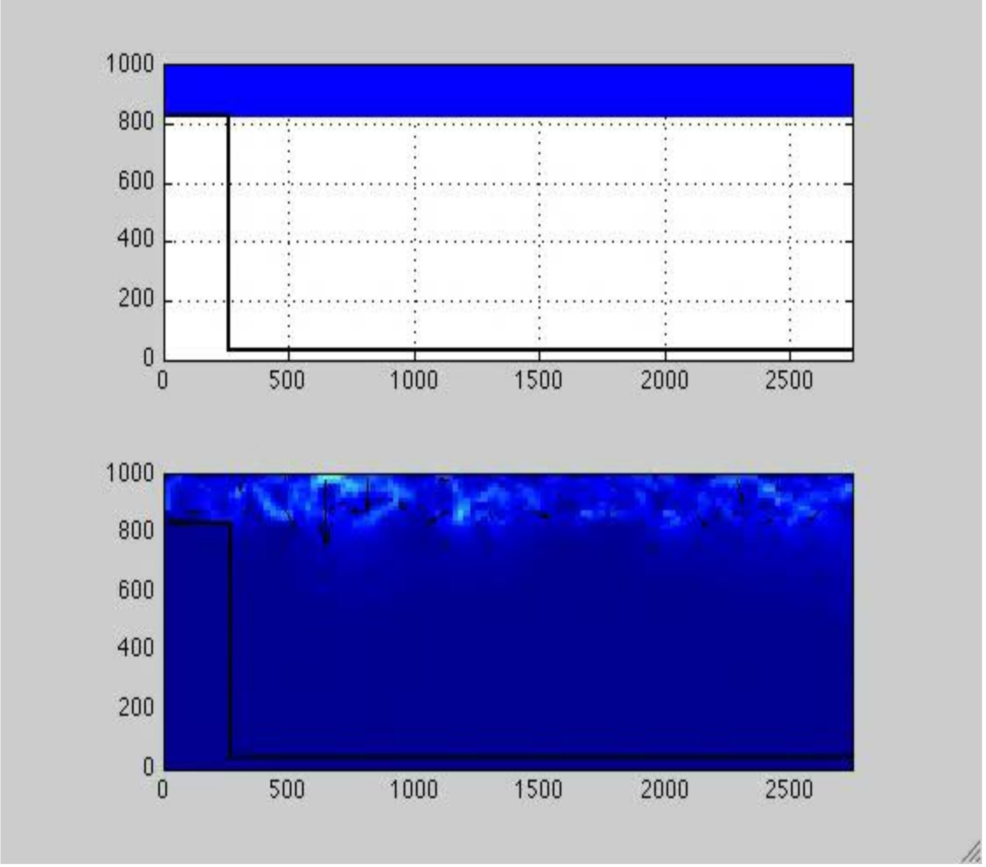
- Polar craters are special thermal and volatile environments
- Cold traps that maintain volatiles
- LCROSS detected 6%wt water (gas and ice) in the impact plume
- LRO/Diviner finds permanently shadowed craters thermally stable environments to maintain water (surface T below desorption temperature)

Table 1. Summary of the total water vapor and ice and ejecta dust in the NIR instrument FOV. Values shown are the average value across the averaging period, and errors are 1 SD.

	Water mass (kg)			
Time (s)	Gas	Ice	Dust mass (kg)	Total water %
0–23	82.4 ± 25	58.5 ± 8.2	3148 ± 787	4.5 ± 1.4
23–30	24.5 ± 8.1	131 ± 8.3	2434 ± 609	6.4 ± 1.7
123–180	52.5 ± 2.6	15.8 ± 2.2	942.5 ± 236	7.2 ± 1.9
Average	53 ± 15	68 ± 10	2175 ± 544	5.6 ± 2.9

Colaprete et al., 2010

DREAM2 team finds:

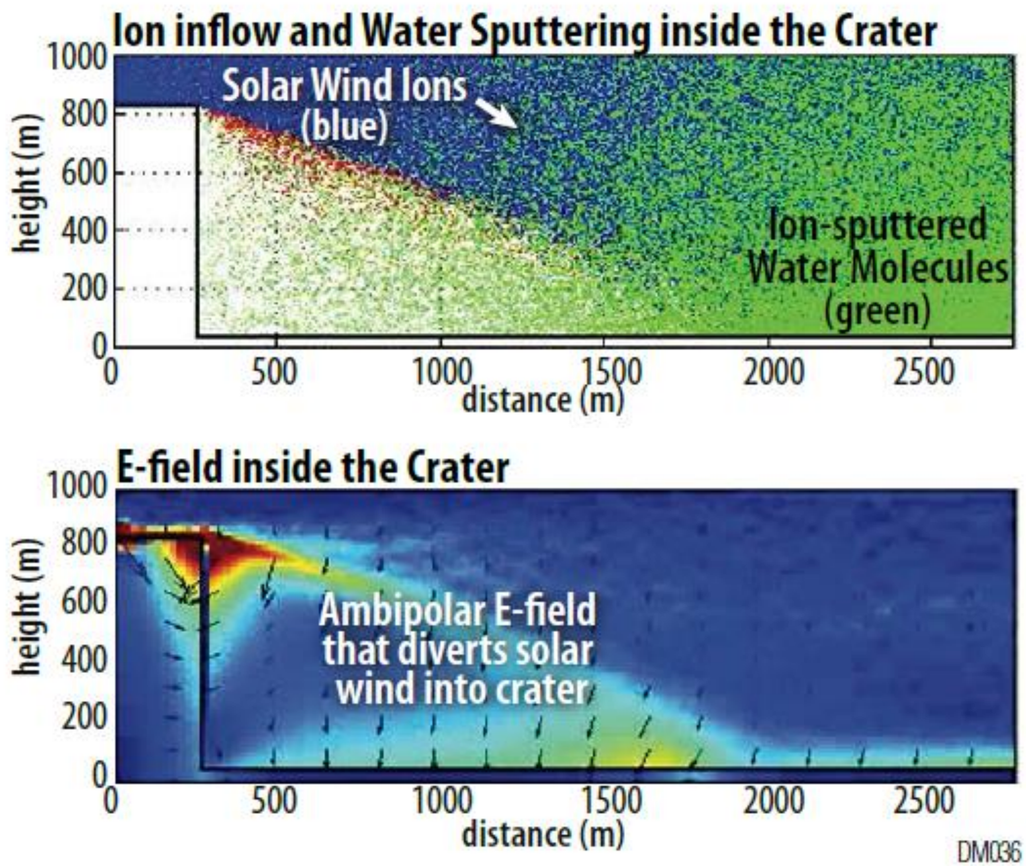


Zimmerman simulation

- Volatiles are thermally stable in polar craters [Paige et al., 2010]
- However, not stable to other elements of space environment
  - Plasma sputtering (ion-surface molecule release)
  - Impact vaporization
  - Lyman-α UV desorption
  - Electron desorption

These are loss processes!

DREAM2 team finds:



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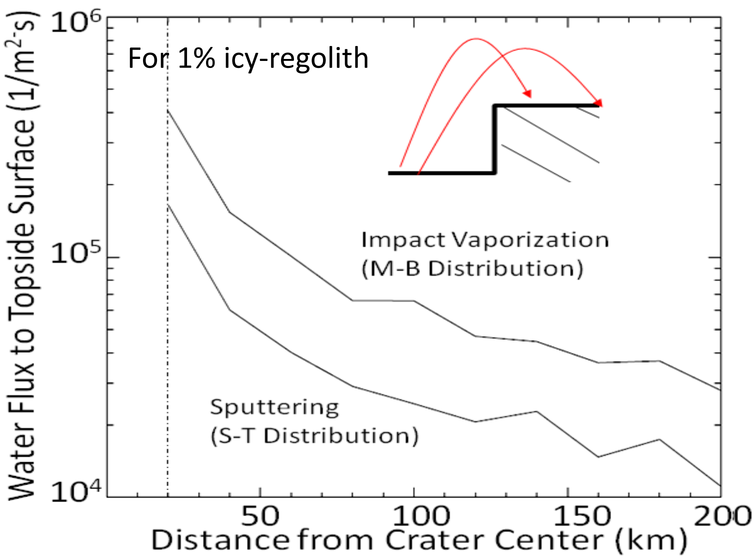
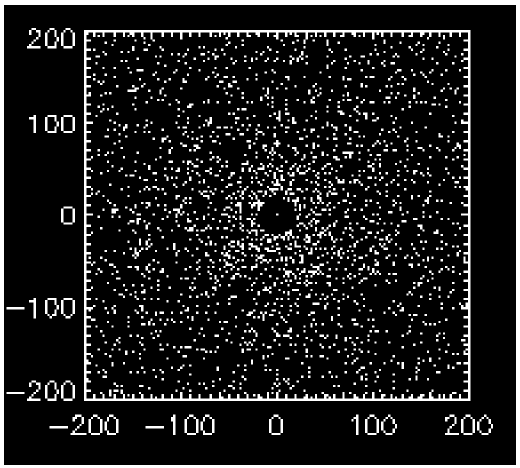
These are loss processes!

Consequence #1: ‘Spillage’ of crater volatiles onto adjacent polar terrain



- The space environment can activate the surface
- Release water to topside terrain
- Monte Carlo models of impact vaporization and sputtering release
- **Prospecting:** Can look along ‘lip’ of crater for material from crater floor…
  - Aid Resource Prospector!
- **Dynamic Equilibrium:** LRO/LAMP detects a light water ‘frost’ on regolith
  - DREAM2 models set water loss rates near $10^8/m^2$-s for 1% icy regolith
  - Dynamic source of water has to exist to offset environmental losses

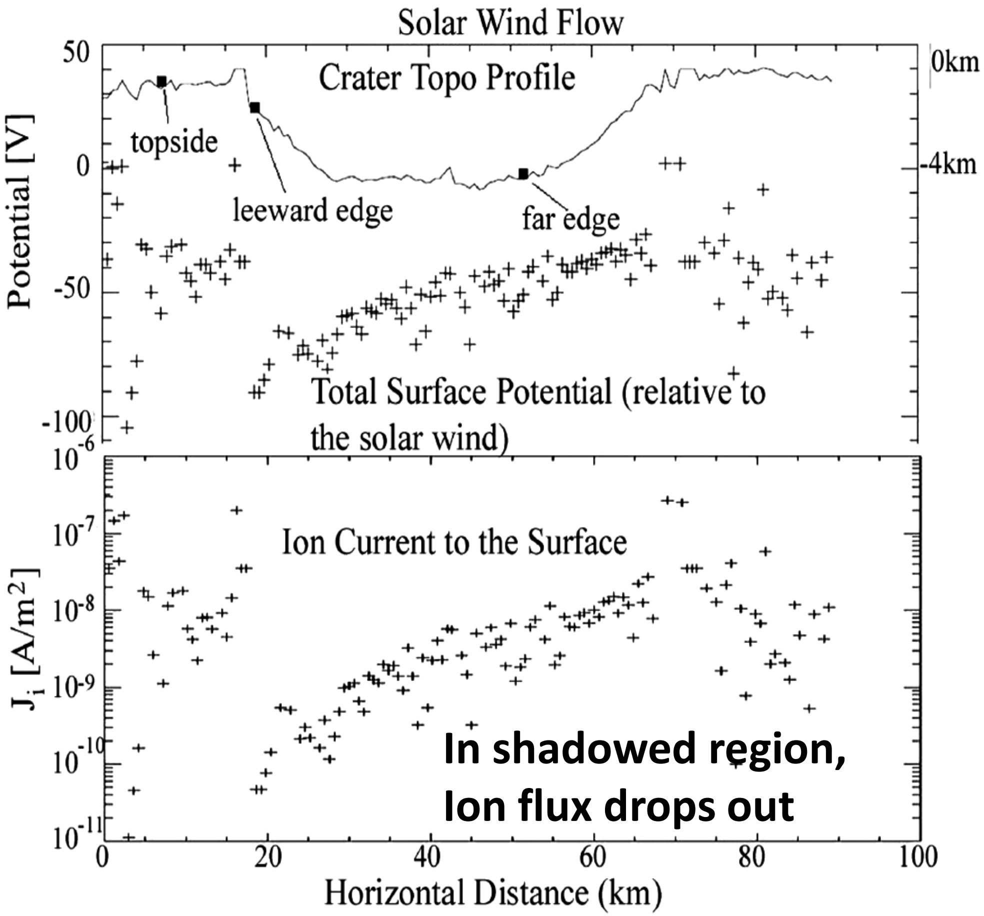
Water test particles in 200 km region about polar crater (via Impact Vaporization)



Presented at AGU 2013, FoLV 2014

Consequence #2: Roving in Lunar Polar Shadowed Regions

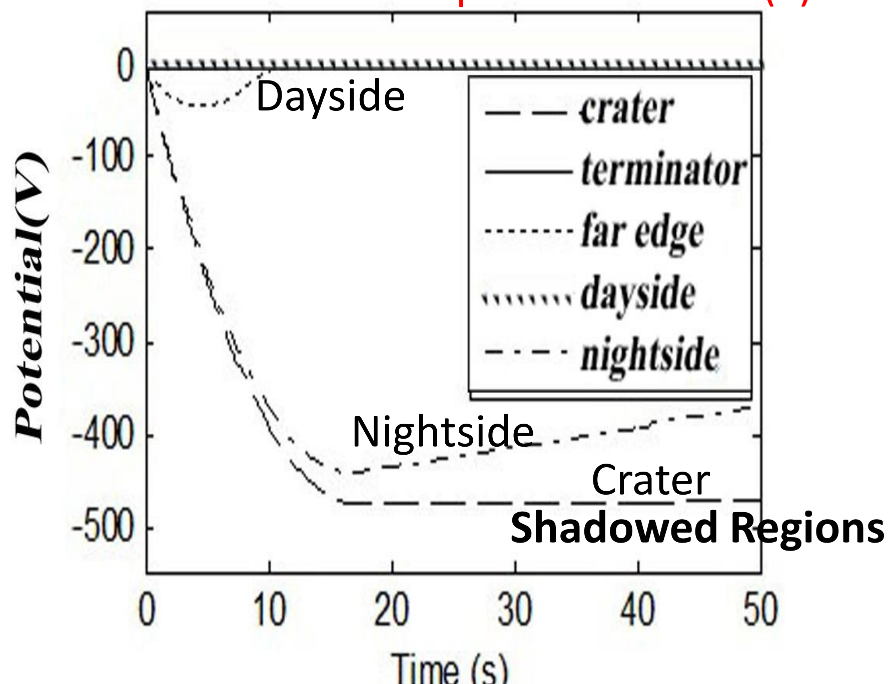
Model of Solar Wind Plasma Inflow into Shoemaker Crater [Jackson et al.. 2011]



Lunar Rover Wheel Charging [Jackson et al., ASR, 2014]

$$dQ/dt = S_{tribo} - L_{plasma} - L_{ground}$$

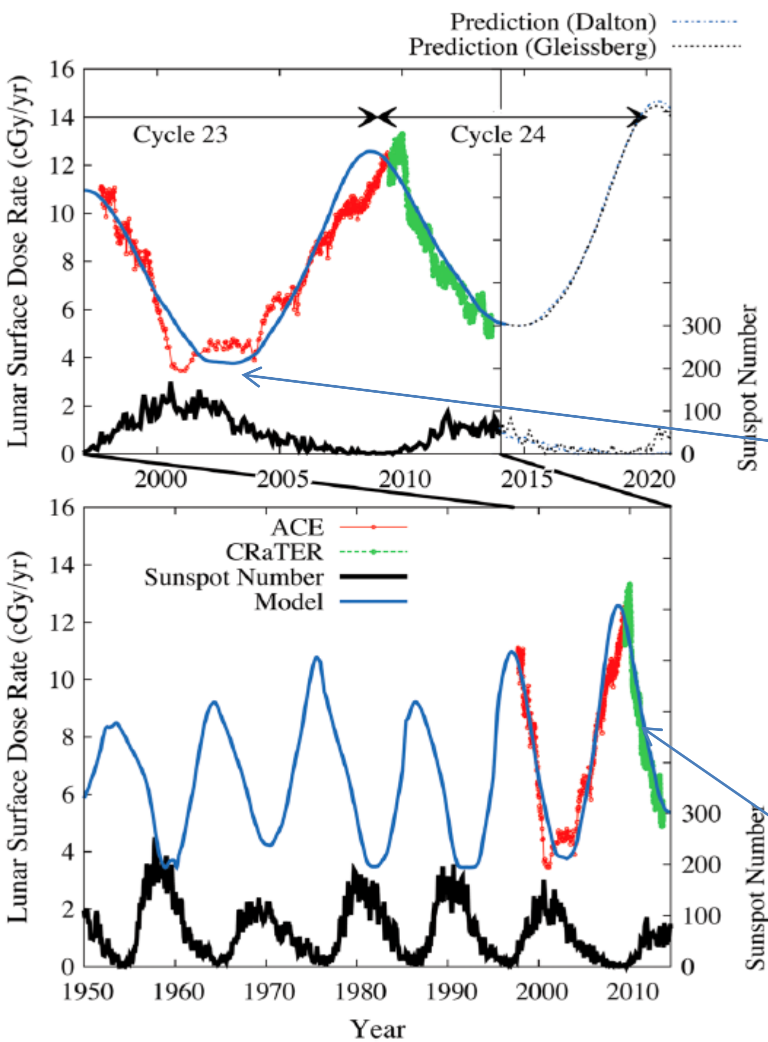
A Resource Prospector concern (?)



Example #3 Key Take-aways

- Besides thermally challenging and chemically complex, DREAM2 team finds that the **lunar polar crater environment electrically complex** …and this integrates into the volatile picture!
- **Benefit:** Material from crater floor is 'hurled' out and onto topside surfaces…don't necessarily have to go into craters (could affect RP operations)
- **Challenge:** Could lose grounding reference of electrical system…no longer well grounded to the plasma (since located in plasma starved location)
  - Recommend: Metallic outer-skin to increase current collecting area
  - Within permanently shadowed craters: maybe even consider a local plasma emitter system that creates a local ground system

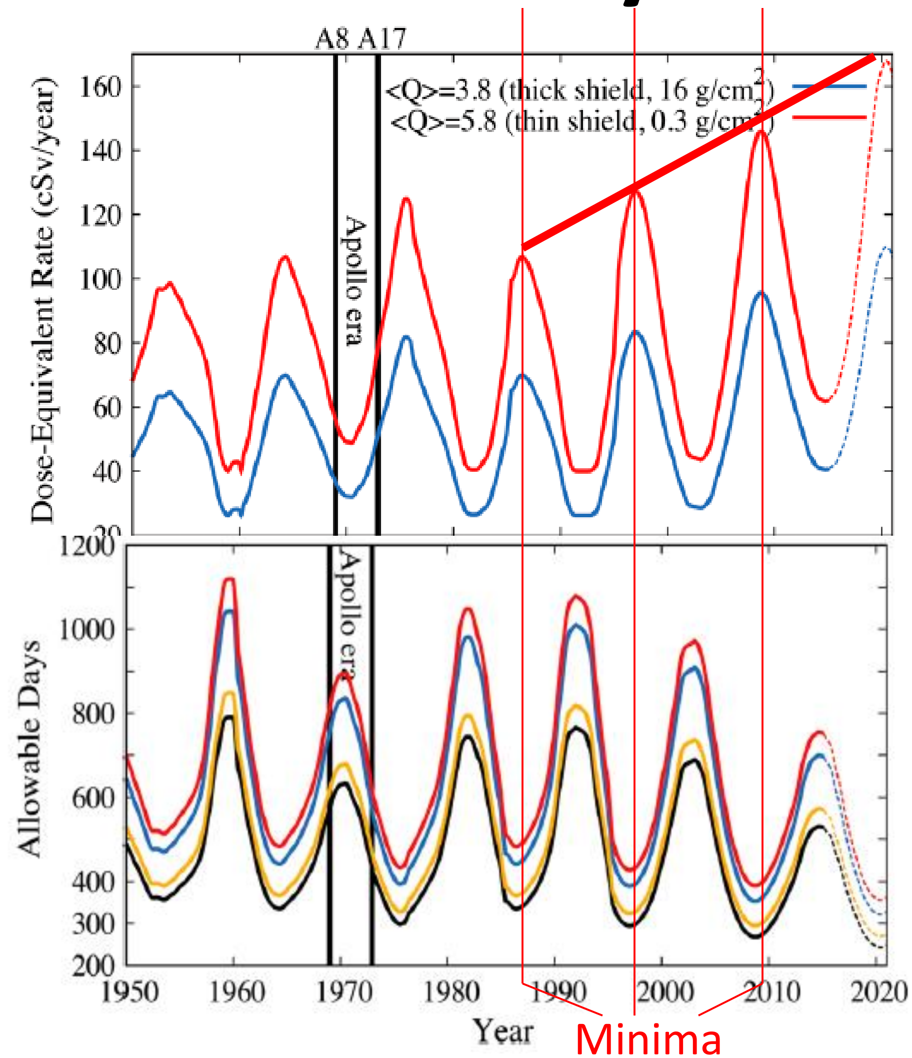
Example #4: Weak Solar Cycles, GCRs, and Allowable Days



- Schwadron et al., 2014, Space Weather
- Galactic comic rays (GCRs): Charged particle radiation peaking ~1000 MeV
- Typically, see solar cycle modulation of GCR flux
- In general, in solar min, (low solar B-field), GCRs can diffuse more easily to inner heliosphere
- **DREAM2 Team Members finds:** Solar B-field over the past few solar cycles diminishing at both max and min
- Sunspot # lower
- Solar minima are deeper now…get more GCR influx

Use LRO/CRaTER integrated with other data sets

Weak Solar Cycles and Allowable Days

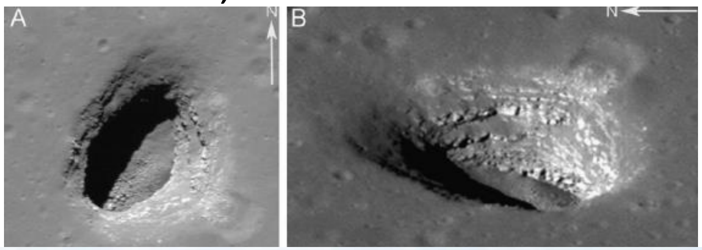


- Schwadron et al., 2014, Space Weather
- Translated GCR flux to allowable time in space based on dose rates
- If trend toward weak solar cycle continues to Cycle 24:
  - at Solar minimum near 2020, GCR flux expected to be very high, reduce allowable days in space to near 200 days
  - But! The next solar maximum near 2030 may be best time to fly – reduced GCR flux due to cycle related B-field increase, but lower probability for a strong solar storm (SEP) event

Allowable days = 3% risk of exposure induced death (REID)

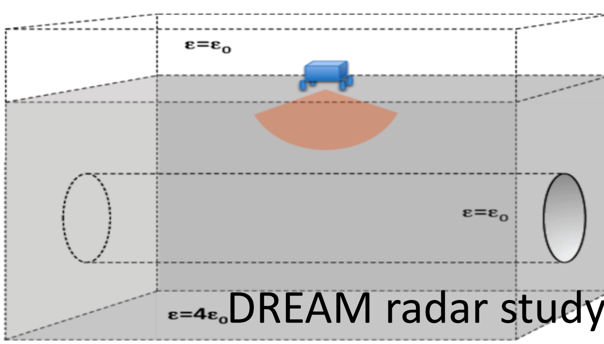
Radiation Safe Havens: Lunar Pit Studies

Robinson et al, 2012 – 220-m wide Mare Ingenii pit

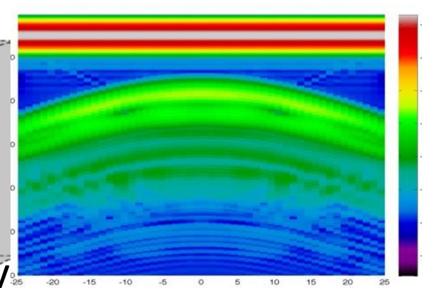


Rise4 field study
Hawaii (GPR, LIDAR)

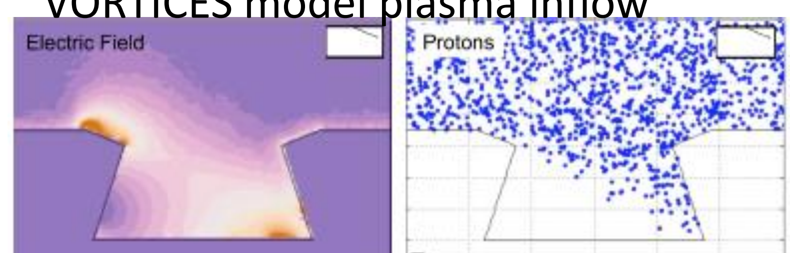
- Combines VORTICES-RISE4-DREAM2 work
- Field work feeds forward to modeling
- Examine:
  - Radiation protection
  - Radar signature
  - Thermal properties
  - Geologic stability
  - Plasma Environment
  - Volatile reservoir



DREAM radar study



VORTICES model plasma inflow



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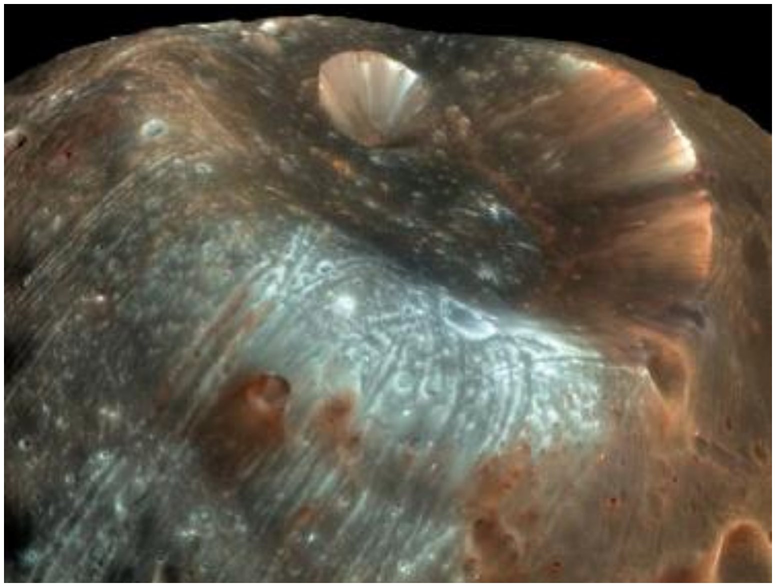
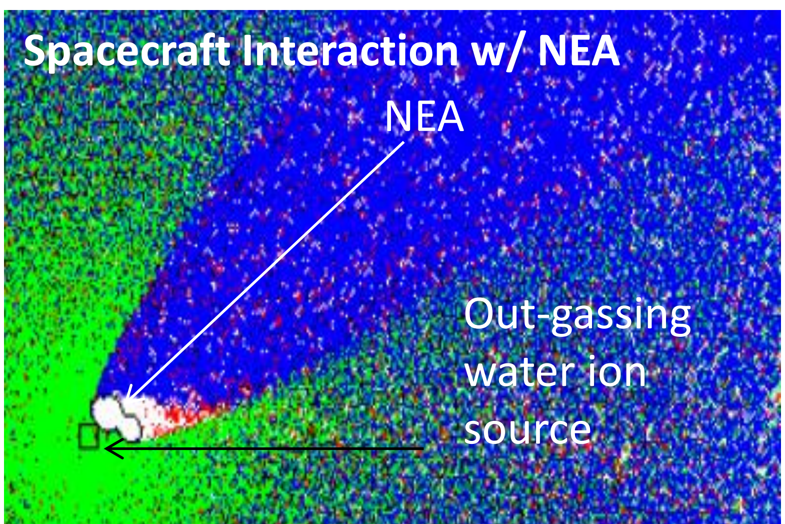
Example #4 Key Take-away:

- As DREAM2 team members examine the radiation environment in a larger temporal context
  - We gain insights on future GCR levels which determine the best times to explore, from an environmental perspective
  - With other teams, examine in detail safe havens from the harsh environment

For Exploration Consideration: Minimum in ‘allowable days’ may occur in 2020, next solar minimum, when GCR flux is largest.

DEEP-er Studies





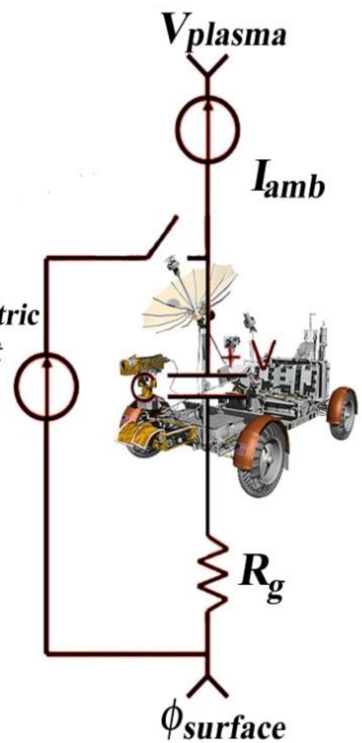
- Intramural focus studies and workshop, integrate models in specific sequence
- Like solar storm at the Moon (SSLAM) study under DREAM
- Include Howard U undergrads interns in support of DEEP
- DREAM2 Extreme Environment Program (DEEP) Focused Studies
  - Solar storm at an NEA
  - First Contact: Orion interaction with fragile environment at an NEA
  - Space environment within Phobos' Stickney Crater

Already developing tactical components for these integrated, strategic studies

Conclusions

- Four examples show DREAM2's environmental science studies are in support of Exploration
- Input on design and operations of Exploration
- DREAM2 studies contribute to issues like:
  - What to wear?
  - Where to touch?
  - When to 'flush'?
  - Where to rove?
  - How fast to rove?
  - What is the weather?
  - When to fly?
  - Where to hide?

Tribo-charging



- It is basic science but impacts exploration implementation
- DREAM2 is truly in the spirit of space environmental science supporting exploration in a tactical sense!...True to the spirit of SSERVI's science-exploration interconnection